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Hideki NAGADOMI Shukichi WATANABE, Yoshirou FUNAYAMA,
Teruo NAKAJIMA, Keisuke KAIEDA

Japan Atomic Energy Research Institute
2-4, Tokai-mura, Naka-gun, Ibaraki-ken 319-1195 JAPAN

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ABSTRACT

JRR-4 had been operated using HEU (93% enriched uranium) fuels since 1965. JRR-4 had consumed all HEU fuels and finished operation using them in January 1996. And JRR-4 modification works had started. The modification works, which were about fuel conversion, installation of a medical irradiation facility, repairing of the building and so on, had successfully completed in June 1998. JRR-4 achieved the first criticality using LEU (20% enriched uranium) fuel on July 141h, 1998 and begun performance tests. The result of performance test was fine and able to get a number of data. This paper presents the modification works and outline of performance tests.

INTRODUCTION

Japan Research Reactor No.4(JRR-4) is a light water moderated and cooled, graphite reflected, pool type reactor with thermal output of 3.5MW. Since the first criticality was achieved using HEU fuels(93% enriched uranium) on January 28 1h, 1965, JRR-4 had been operated safely for wide utilization such as nuclear shipment reactor shielding experiment, fuel and nuclear material irradiation experiment, radio isotope production, nuclear activation analysis, silicon transmutation doping, reactor school training and etc.. JRR-4 consumed all HEU fuels. JRR-4 terminated operation using them on January 12^{th} , 1996. Total thermal power is 58,706MVvh, and total operating time is 29,377hours. Bird's-eye view of JRR-4 core is shown in Figure-1.

The modification of JRR-4 was planned about core conversion according to the framework of reduced enrichment for research reactor program, utilization facilities upgrading, renewal of some reactor systems, repairing of the building, installation of a medical irradiation facility.

The design and evaluation for LEU core were done based on the guide for safety design and evaluation of research and test reactor facilities in Japan. Neutronic and thermalhydraulic performance were calculated, which were presented at RERTR meeting already in detail.

Modification works were carried out after design, safety evaluation and licensing review, form 1996 to 1998 for about 2 years.

MODIFICATION WORKS

The license for modification of JRR-4 was issued in September, 1996. Modification works was successfully carried out from October 1996 to June 1998, according to the scheduling program.

Objectives of the modification of JRR-4 were to convert from HEU fuel to LEU fuel, to remodeling of some reactor systems based on safety evaluation and to upgrade utilization facilities for medical irradiation etc..

Modification works were treated as follows

- Fuel conversion

- New installation system
  - Emergency exhausting system
  - Fuel failure monitor for major accident

- Renewal
  - Reactor instruments and control systems
  - Control rod and control rod drive system
  - Emergency electric power supply system

- Repairing of reactor building on a seismic design
  - Remodeling of roof structure
  - Reinforced of some pillars and walls

- Upgrading of utilization facilities
  - Installation of medical irradiation facility, for BNCT
  - Neutron activation analysis system for shorter life nuclides
  - A large pipe irradiation system for silicon doping etc.

Schedule for modification works is shown in Figure-2.

FUEL CONVERSION

According to the Reduced Enrichment for Research and Test Reactors program, the fuel was changed from 93% high enriched uranium aluminized fuel(HEU) to 20% low enriched uranium silicide fuel (LEU) with 3.8g/cm', however the reactor performance was calculated same thermal power without changing of structure, size and number of fuels in the core. Specification of LEU fuel element is shown in Table-1. The fuel elements were fabricated by BWXT in USA. About 600 fuel plates were produced, and 35 fuel elements were fabricated.' On process of fabrication, many kinds of inspection were performed, as follows. Several inspections were performed strictly by Science and Technology Agency(STA) in Japan. The fuel elements ware delivered from USA to JAERI in June, 1998.

- Physical inspection for materials

- Visual inspection for plates and fuel elements

- Calculation uranium silicide compact charge and 235U content Blister annealed inspection

- Immersed ultrasonic inspection
- Radiographic technique and film interpretation for core location and stray particle evaluation
- Dimensional inspection
- Alpha count fuel plates and fuel elements
- Role swage

DESIGN AND EVALUTION FOR LEU CORE

Design and evaluation of JRR-4 LEU core were calculated with several code systems in JAERL The SRAC code and MW code were used for neutronic them. The COOLOD code, THYDE-W code and EUREKA-2 code were used for thermal- hydraulic them.

The new LEU core has the performance for thermal neutron flux level (7xlO"n/cm'/sec) as same as HEU core, without major change of structure and size of fuel element and core dimensions. The JRR-4 core configuration after modification works is shown in Figure-3.

The JRR-4 core is composed 8x8 array with fuels, reflectors, control rods, neutron source and irradiation pipes. The fuel elements are arranged in a 4x5 array and surrounded by reflectors. The reflectors are made by graphite and aluminum. 3 graphite reflectors closed to medical irradiation facility are replaced to aluminum one, to increase neutron flux for BNCT. The control systems consists of shim control rod(C1-C4), regulating rod(C5), and safety rod(Bl,B2). There are 5 irradiation pipes. The largest one was expanded for more bigger samples.

On thermal-hydraulic design, the core coolant flow rate is increased from $7m^3$/min to $8m^3$/min by three main pumps because a safety margin of fuel is increased in case of power cut.

OUTLINE OF PERFORMANCE TEST

The performance test was carried out for about 3 months, from July to September, 1998.

Objectives of performance test were to achieve first criticality using LEU fuels, to measure reactivity, to confirm of JRR-4 safety, to measure characteristics and so on. The topics and schedule of performance test is shown in Figure-4.

Performance test was planned for about one year by three groups, two neutronic characteristic measurement groups and one thermal-hydraulic characteristic measurement group.

After the modification works, preparation for performance test was started, and the critical approach experiment was stared in July 13^{th} , 1998. The first criticality was achieved on July 14^{th}, and loading of 20 fuel elements, standard core constitution, was finished on July 16^{th}.

- Critical Approach

First, 6 fuel elements were loaded into the core and graphite reflectors were loaded another fuel region instead of fuel elements. The critical approach experiment was stared using 6 fuel elements. Next, fuel elements were replaced to reflectors one by one. The minimum criticality was achieved using 12 LEU fuel elements, and critical state was kept without neutron source. The inverse multiplication for first criticality is shown in Figure-5. Loading of fuel elements were continued until 20 elements were in the core.

- Control Rod Calibration

Control rod calibration were performed with the positive period method and the comparison method. Control rod worth of LEU core was almost same value compare with HEU core. Excess reactivity and one rod stuck margin were calculated from control rod worth. It was confirmed that safety margin of control rod worth was enough.

- Measurement of Neutron Flux and Distribution

Thermal neutron flux were measured. Au, Au covered by Cd and Cu were irradiated for measurement of them. The maximum thermal neutron flux was about 5.5×10^{13} n/cm'/sec at 3,5OOkW. The peak of neutron flux on vertical direction were appeared at about 150mm position from bottom of fuel meat. The cadmium ratio was 2.46.

- Measurement of Dynamic Characteristic Parameter

The core temperature coefficient, which synthesized moderator temperature and fuel temperature, was measured. In this case, JRR-4 was operated with thermal output 10OW The moderator temperature was increased about 20'Cby changing secondary coolant temperature by steam.

Mass reactivity coefficient was measured at some location in the fuel region.

The moderator void reactivity coefficient were measured. In this experiment, to make void in moderator, styrene foam were inserted into channels in the fuel elements.

It was confirmed that these parameters had negative value.

- Measurement of Coolant Flow Rate Distribution in the Core

On design and safety evaluation of JRR-4, the flow rates of fuel region was 86% of total coolant. At forced convection mode operation, total coolant flow rate is 8m/min.

The test element which structurally similar to fuel element made from aluminum with differential pressure type flow meter were replaced to fuel elements. In this case, only cooling system was operated. The result of measurement, it is confirmed that about 87% of coolant flow in the fuel region.

- Experiment of Power Up to 200kW (with natural convection)

The experiment of power up to 200kW with natural convection were performed. It was confirmed that the core was cooled enough with natural convection. The neutronic behavior was stabilizing very much.

Fuel surface temperature were measured. Thermocouples were put on the fuel inner plate surface. Temperature which measured at this case was lower than temperature which was used at evaluations.

- Experiment of Power Up to 3,5OOkW (with forced convection)

The experiment of power up to 3,5OOkW(maximum power) with forced convection was performed. JRR-4 was operated with six steps, 20W, 50kW, 100kW, 200kW, 1,000kW and 3,500kW. Power was raised step by step after thermally state became steady. After power calibration at 1,000kW, power was raised to 3,500kW. Operation with 3,5OOkW thermal output was achieved in September 16 1h, 1998.

On through the experiment of power up to 3,500kW, fuel failure was not detected. The radio activities in coolant through the high power operation was measured. Fission products was not released from fuel plates to coolant. It was confirmed that fuel elements were good condition through fabrication, loading, high power operation and so on. Dosimetry was performed all area of JRR-4 by area monitors and dosimeters. It was confirmed shielding have sufficient capability.

Thermal-hydraulic characteristics were measured. The coolant temperature of core outlet were about 33°C and not exceed 60°C (limited temperature on permission of JRR-4).

It was confirmed that JRR-4 cooling system have sufficient cooling capability at high power operation.

CONCLUSION

The fuel conversion and the modification works had successfully completed. And a number of important data for operation of JRR-4 and its safety were measured and confirmed.

Measurement and process of some characteristics have not been completed, yet. It is planned that they will be done soon.

After performance test of utilization more three months, the operation for users will be started in January, 1999.

ACKNOWLEDGMENTS

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Table-1 Specification of Fuel

Item	LEU Fuel Element	HEU Fuel Element
Type	MTR	ETR
Enrichment(%)	20	93
Content of U per element(g)	1020	179
Content of U235 per element(g)	204	166
Number of fuel plate per element	15	15
Fuel meat material	U_3S_2-Al dispersion	UAl_x-Al
Cladding material	Aluminum alloy	Aluminum alloy
Cladding thickness(mm)	0.38	0.38
Maximum burn-up ratio(%)	50	20
Size of fuel element(mm)	80Wx80Lx1025H	80Wx80Lx1025H

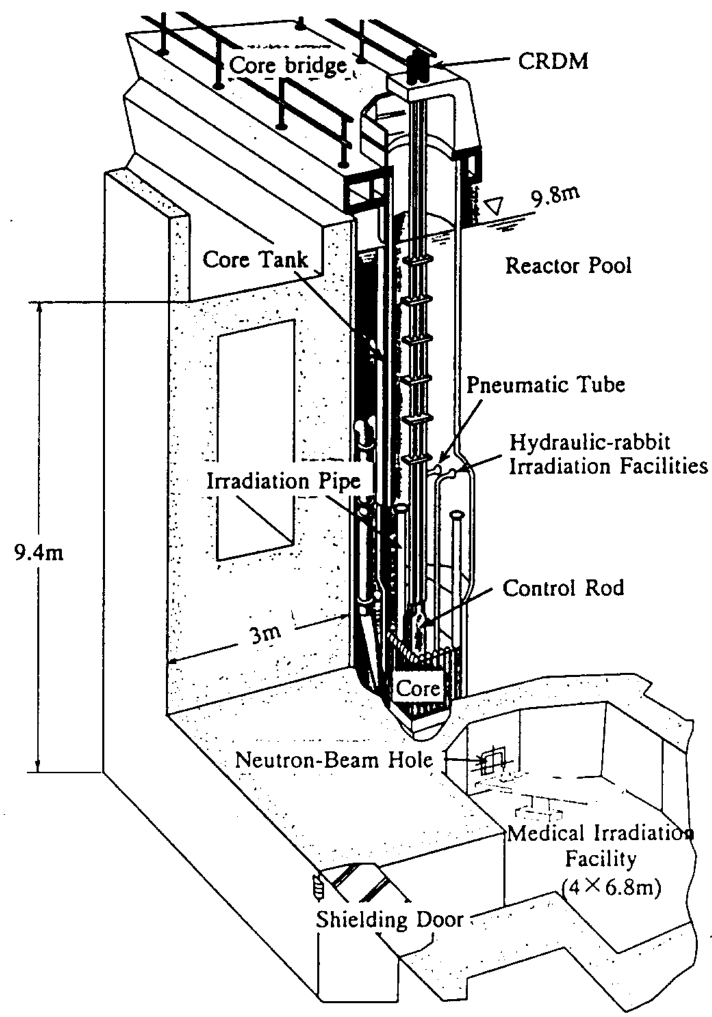

Figure 1 Bird’s-eye view of JRR-4 reactor

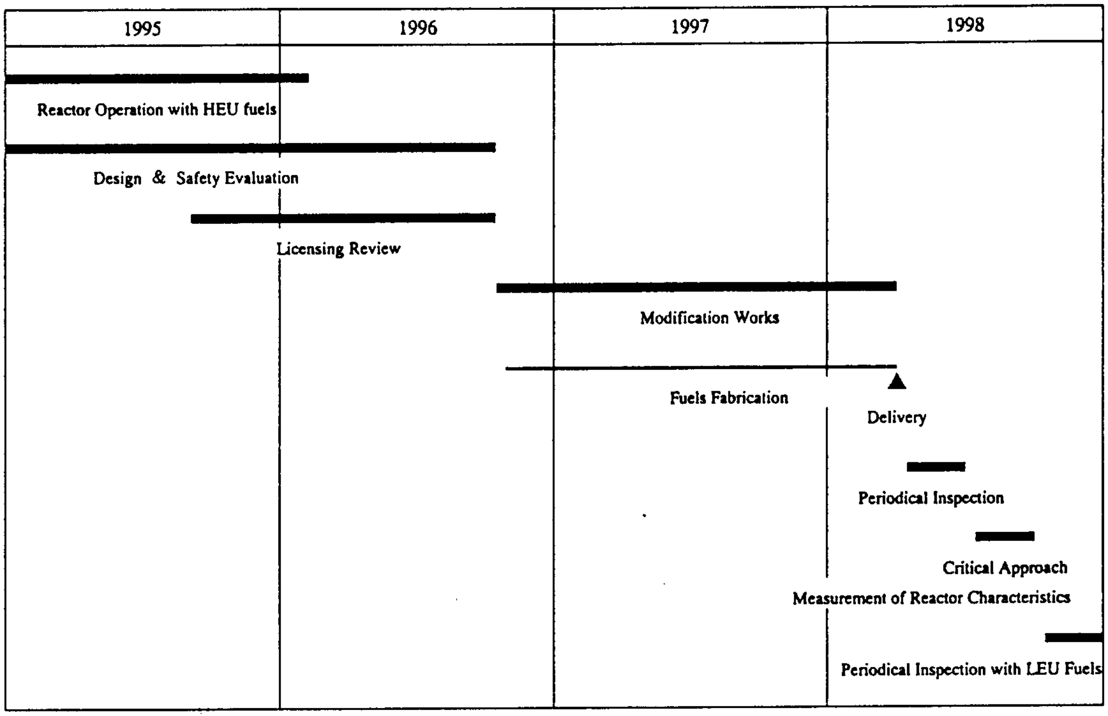

Figure-2 Schedule for modification works

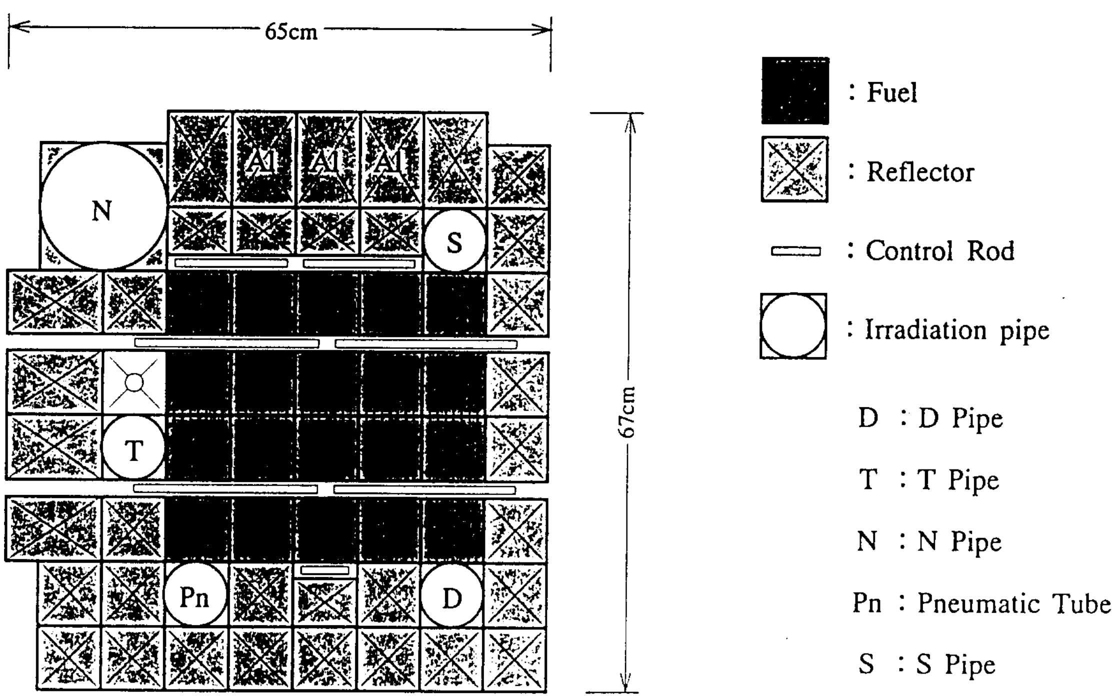

Figure-3 JRR-4 core configuration

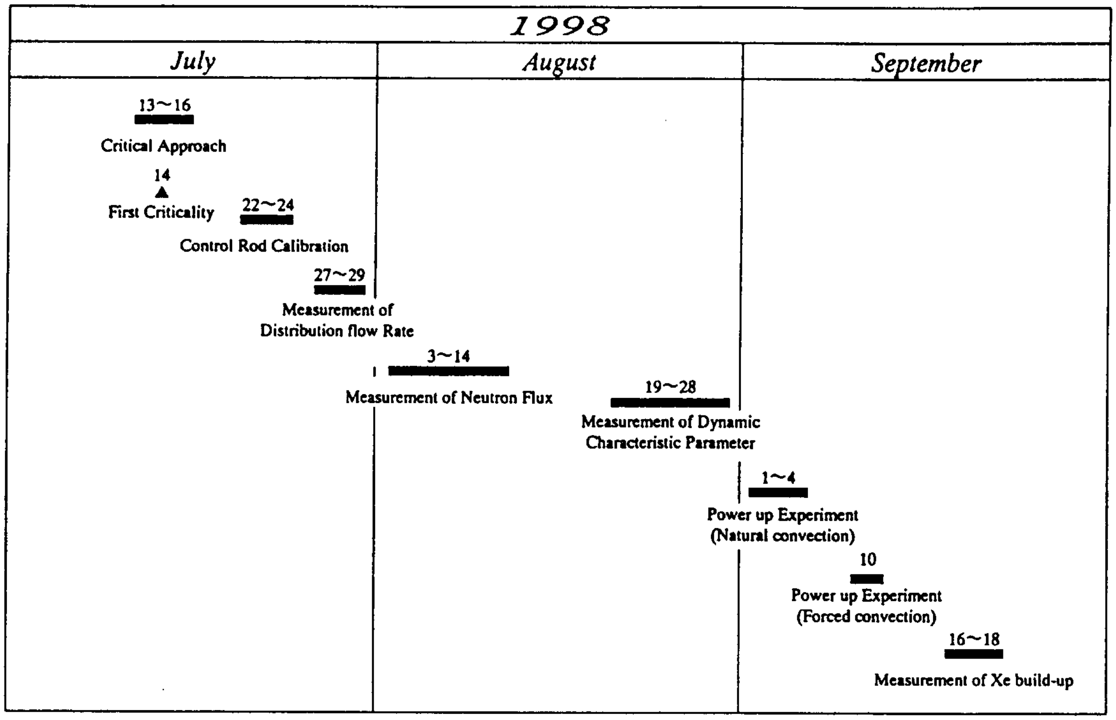

Figure-4 Schedule for performance test

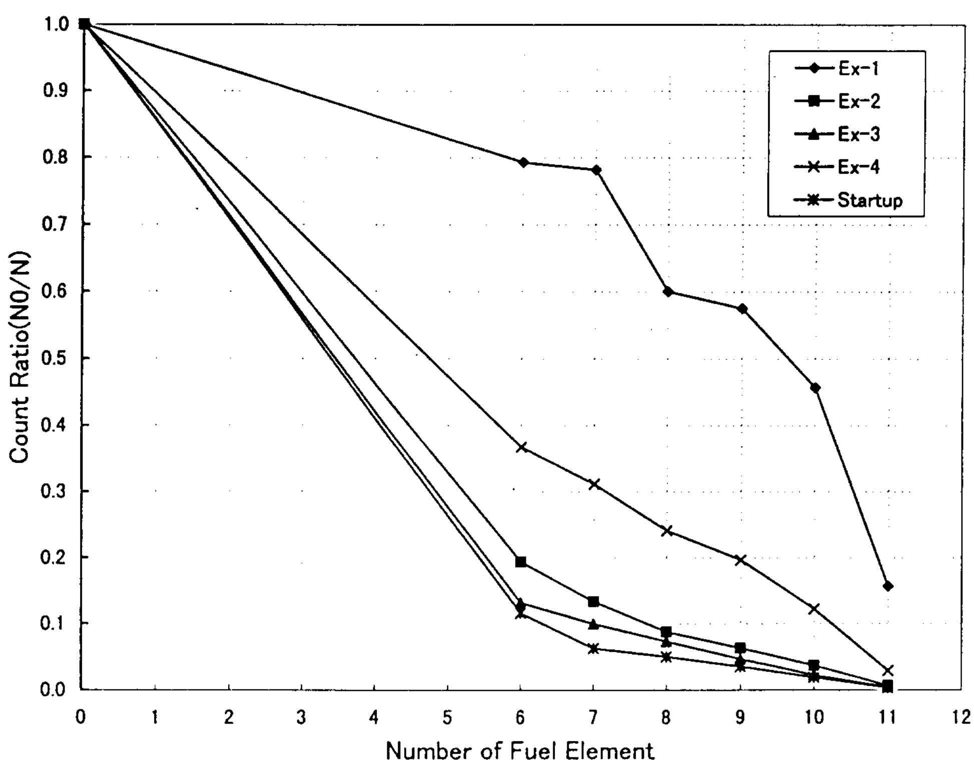

Figure-5 The Inverse Multiplication for the First Criticality